


		Document:		223500-00-SC008		
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ENEL FUSINA - CHEMICALS AUXILIARIES OF SCR - AMMONIA SOLUTION STORAGE DESIGN PROCESS CALCULATION REPORTS						
REV.	DATE	DESCRIPTION	SIGNATURES			
			Issued	Checked	Approved	
00	27/06/2022	First Issue	CH	AM	SL	
01	09/08/2022	Revised after comments	CH	AM	SL	

SUPERVISION OUTCOME <i>Esito Supervisione</i>			APPROVED							
01	13/09/22	ES	a264116	GB					a264116	A242906
REV	DATE <i>Data</i>	Issue <i>Scope</i>	SUPERVISED <i>Esaminato</i>	CO-OPERATIONS <i>COLLABORAZIONI</i>					APPROVED <i>Approvato</i>	ISSUED <i>Emesso</i>
 ENGINEERING AND CONSTRUCTION			Document no / Documento PBCFU58305					Security Index <i>Indice Sicurezza</i> Internal Use / P		
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SYSTEM <i>Sistema</i>	HSJ	APPL. TO SECT. <i>Valido per sez.</i>	7	DOC. TYPE <i>Tipo doc.</i>	SF	DISCIPLINE <i>Disciplina</i>	P	FILE <i>File</i>	PBCFU58305.pdf	
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PROJECT <i>Progetto</i>			FUSINA - CAPACITY MARKET ITALY							
CLIENT <i>Cliente</i>			ENEL PRODUZIONE S.p.A.							
JOB no : M040			Doc. no. PBCFU58305							
CLIENT SUBMITTAL <i>Inoltro al Cliente</i>			<input checked="" type="checkbox"/> FOR APPROVAL <i>Per approvazione</i>		<input type="checkbox"/> FOR INFORMATION <i>Per informazione</i>		<input type="checkbox"/> NOT REQUESTED <i>Non richiesto</i>			


DESIGN PROCESS CALCULATION REPORTS

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01	09/08/2022	Revised after comments	CH	LR	SL

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1 SCOPE

This document describes the design criteria of the ammonia solution unloading, storage and circulation system to be installed in ENEL's power plant "Andrea Palladio" in Fusina (VE), Italy.

2 REFERENCE DOCUMENTS

- | | |
|---------------|--|
| a. PBCFU60030 | PTS – Ammonia Solution Storage Sys – General |
| b. PBCFU58318 | P&ID Ammonia System |
| c. PBCFU58319 | P&ID Ammonia Leak Detection & Rain Abatement System |
| d. PBCFU58320 | P&ID Potable, Demi and Industrial Water Systems |
| e. PBCFU58321 | P&ID Service Air and Instrument Air Systems |
| f. PBCFU58322 | P&ID Nitrogen System |
| g. PBCFU58323 | P&ID Ammonia Drains, Collecting System and Final Discharge Basin |
| h. PBCFU58324 | Process Flow Diagram (PFD) |
| i. PBCFU58311 | General Plot Plan & Key Plan |

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3 DESIGN CRITERIA

3.1 Ammonia Solution General Information

Ammonia utilized for the SCR system is transported as an aqueous solution (24,9% w/w) by trucks and unloaded into the storage tanks (76HSJ21BB100 / 76HSJ22BB100) on site by means of dedicated unloading pumps (76HSJ11AP100 / 76HSJ12AP100).

Aqueous ammonia is classified, according to European Directives n° 45/1999, dangerous for the environment (abbreviation "N") and very toxic to aquatic organisms (abbreviation "R50") only if NH₃ content is above 25% by weight. The same is based on the more recent classification according to European Regulation n° 1272/2008: Very toxic to aquatic life, toxicity acute, category 1 (abbreviation Aquatic Acute 1, H400) only if NH₃ concentration is above 25% by weight.

Even if using an ammonia solution concentration below 25%, the same safety and reliability must be assured in the design, construction, operation and maintenance of the installation, as required for more concentrated ammonia solutions.

Ammonia storage tanks (76HSJ21BB100 / 76HSJ22BB100) shall be vented via a fume scrubber (76HSJ30BB100) to prevent any gaseous ammonia emission during loading operations and due to temperature variations. Vacuum conditions inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) while feeding ammonia to the evaporators shall be prevented by means of a N₂ blanketing system that will ensure pressure to fall inside a specific range. Intake of air through the vacuum breaker valves shall be avoided.

3.2 Unloading system general requirements


The unloading system is equipped with:

- a mechanical swivel pipeline to connect the truck to the unloading tank (76HSJ10BB100)
- an unloading tank (76HSJ10BB100) to avoid cavitation of the unloading pumps (76HSJ11AP100 / 76HSJ12AP100)
- unloading pumps (76HSJ11AP100 / 76HSJ12AP100), 2 x 100%
- connection pipelines for ammonia solution and connection pipelines for gases to balance pressure inside tanks

The unloading tank (76HSJ10BB100) vent (gas pipeline) is connected to the fume scrubber (76HSJ30BB100) to capture any gaseous ammonia produced. Inbreathing will be guaranteed via N₂ injection, to prevent air from entering the system.

Unloading operations will be managed locally, via a local panel located in the unloading area. The unloading pumps (76HSJ11AP100 / 76HSJ12AP100) are redundant (2 x 100%), one pump in operation and the other one as backup. Each pump is sized to guarantee unloading a truck (30 m³) in no more than 30 min.

The mechanical swivel pipeline is equipped with an isolation pneumatic valve on each pipeline (liquid discharge and gas return), fail close. In case of pipeline damage, the system interrupts air to the valves' actuator to immediately close the isolation valves and stop unloading pump.

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3.3 Storage and Circulation System General Requirements

The storage and circulation system is equipped with:

- storage tanks (76HSJ21BB100 / 76HSJ22BB100), 2 x 100%
- circulation pumps (76HSJ21AP100 / 76HSJ22AP100), 2 x 100%
- pressure control valve (76HSJ20AA051)
- connection pipelines for ammonia vapors to balance pressure inside tanks

Storage tanks (76HSJ21BB100 / 76HSJ22BB100) are designed for the following conditions: T=50°C, 0.45 barg overpressure, 0.05 barg vacuum. The fume scrubber (76HSJ30BB100) shall be sized to guarantee an operating pressure not exceeding the design range. Storage tanks (76HSJ21BB100 / 76HSJ22BB100) are redundant (2 x 100%) and completely interchangeable, each with a nominal capacity of 100m³. The spare storage tank will be kept empty all the time. The tanks are installed inside a closed and ventilated structure to protect them from solar radiation and are equipped with vacuum breakers to protect them from vacuum.

The storage tanks (76HSJ21BB100 / 76HSJ22BB100) are installed inside a containment basin which discharges by gravity in a final discharge basin (useful volume 70m³). Connections for N₂ blanketing are provided for pipelines and tanks.

Circulation pumps (76HSJ21AP100 / 76HSJ22AP100) (2 x 100%) circulate ammonia inside a closed ring, having a feed line to the SCR evaporators. The pressure control valve (76HSJ20AA051), located in the recirculation line, balances any flow rate variation due to different ammonia flowrates required by the SCR system.


NH₃ gas emissions are detected by suitable sensors located in positions where a potential emission could occur. In case of NH₃ detection, the system enables dedicated deluge valves to provide water for ammonia gas abatement. The detection system foresees an alarm when the ammonia concentration is in the range between 50 – 100 ppmv and enables the dedicated deluge valves when the concentration exceeds 200 ppmv. All gas detectors shall be connected to a local ammonia detection control panel.

3.4 Fume scrubber (76HSJ30BB100) General Requirements

The fume scrubber system is equipped with:

- fume scrubber (76HSJ30BB100), 1 x 100%
- recovery pumps (76HSJ31AP100 / 76HSJ32AP100), 2 x 100%
- connection pipelines for ammonia vapors and water feed

Storage tanks (76HSJ21BB100 / 76HSJ22BB100) and unloading tank (76HSJ10BB100) vents are interconnected and sent to the fume scrubber (76HSJ30BB100) tank. Venting of the system shall be via the fume scrubber (76HSJ30BB100), which acts as a hydraulic guard, sized for the most severe conditions in terms of flow and pressure/temperature of the solution. The fume scrubber (76HSJ30BB100) shall be sized so that a maximum ammonia concentration of 5%w/w is reached in 2 months, considering the unit in continuous operation at MCR with design NO_x content, T according to each site's environmental conditions and an ammonia solution concentration of 25%w/w.

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Ammonia recovery pumps (76HSJ31AP100 / 76HSJ32AP100) (2 x 100%) with a design flowrate of 10m³/h are used to send the contents of the fume scrubber (76HSJ30BB100) into one of the storage tanks (76HSJ21BB100 / 76HSJ22BB100). A recirculation line on the pump discharge is present to homogenize contents inside the fume scrubber (76HSJ30BB100).

3.5 Nitrogen Blanketing General Requirements

The nitrogen system is equipped with:

- nitrogen bottles' storage area
- No. 3 pressure reducers (76QJD10AA051 / 76QJD10AA052 / 76QJD10AA053)
- nitrogen bottles connections and distribution pipelines


Nitrogen for storage tank blanketing is provided by means of high-pressure bottles. No automation is involved in the nitrogen system. Pressure reducing valves automatically feed nitrogen inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) when pressure drops below a defined value.

3.6 Containment Basin General Requirements

The containment basin system is equipped with:

- containment basin for storage tanks (76HSJ21BB100 / 76HSJ22BB100) and fume scrubber (76HSJ30BB100)
- final discharge basin (useful volume 70m³)

The containment basin is sized to hold 1,5 times the volume of one full ammonia storage tank and discharges by gravity to the final discharge basin. The final discharge basin is sized to hold the contents of one ammonia truck (30m³) plus ammonia abatement water.

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4 INPUT DATA

4.1 Ammonia Solution (25%w/w) Characteristics

- Chemical name: Ammonium hydroxide aqueous solution
- Chemical formula: NH_4OH
- Molecular weight: 35,05 g/mole
- Physical state: Liquid
- Color: Colorless
- Solubility in water: Completely soluble
- Density: 0,903 g/cm³ @ 20 °C
- Melting point: -57,5 °C
- Boiling point: 37,7 °C @ 1,013 hPa
- Lower Flammable Limit: 15,4% v/v
- Upper Flammable Limit: 33,6% v/v


4.2 Process Input Data

The ammonia solution unloading, storage and circulation system shall feed an SCR unit and guarantee the following:

- NH_3 solution flowrate at storage system battery limits → 400 L/h
- NH_3 solution pressure at storage system battery limits → 5 / 7 barg (min / max)

Input requirements for other equipment include:


Ammonia Solution Unloading Tank (76HSJ10BB100)	3 m ³ useful volume
Ammonia Solution Storage Tanks (76HSJ21BB100 / 76HSJ22BB100)	100 m ³ useful volume (each)
Fume scrubber (76HSJ30BB100)	10 m ³ useful volume
Ammonia Solution Unloading Pumps (76HSJ11AP100 / 76HSJ12AP100)	60 m ³ /h (min)
Ammonia Unloading Drain Pumps (76HSJ41AP200 / 76HSJ42AP200)	20 m ³ /h (min)
Ammonia Solution Circulation Pumps (76HSJ21AP100 / 76HSJ22AP100)	1,2 m ³ /h
Ammonia Recovery pumps (76HSJ31AP100 / 76HSJ32AP100)	10 m ³ /h
Sump pumps (76HSJ41AP100 / 76HSJ42AP100)	30 m ³ /h (min)

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Ammonia solution shall be discharged from the truck only by gravity. Unloading pipeline and layout shall be designed to guarantee an unloading time not exceeding 30 minutes.

The fume scrubber (76HSJ30BB100) shall be sized so that a maximum ammonia concentration of 5%w/w is reached in 2 months, considering the unit in continuous operation at MCR with design NO_x content, T according to each site's environmental conditions and an ammonia solution concentration of 25%w/w.

The Final Discharge Basin useful volume shall be 70 m³.

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5 AMMONIA STORAGE SYSTEM

5.1 Ammonia Solution Consumption

Ammonia solution consumption to be guaranteed for the SCR unit operating at MCR is 400 L/h.

5.2 Storage tanks (76HSJ21BB100 / 76HSJ22BB100)

The useful storage capacity of each storage tank is 100 m³.
Each tank shall be vented to the fume scrubber (76HSJ30BB100).

Storage tanks (76HSJ21BB100 / 76HSJ22BB100) design criteria:

- Tank volume: 100 m³ useful volume
- Duty: 2 x 100%
- Venting system: to fume scrubber (76HSJ30BB100)
- Vacuum protection: vacuum breaker valve
- Design pressure: 0,45 barg (overpressure) / 0,05 barg (vacuum)
- Design temperature: 50°C
- Material: AISI 304L


5.3 Ammonia solution circulation pumps (76HSJ21AP100 / 76HSJ22AP100)

The ammonia circulation station includes no. 2 pumps, working in a 2 x 100% configuration. Circulation pumps (76HSJ21AP100 / 76HSJ22AP100) feed the SCR unit ammonia evaporator. The following common data is used for pump sizing:

- Pump discharge piping size: 1"
- Pump discharge flowrate: 1200 L/h
- Pressure losses at pump suction: 2 m
- Flowrate to SCR evaporation unit: 400 L/h
- Pipe size to SCR evaporator: 3/4"
- Length of pipe to SCR evaporators: ~250 m (to be confirmed after piping layout)
- No. of 90° bends: 15 (to be confirmed after piping layout)

Circuit's maximum head loss SCR evaporator → ~ 10,9 mWC

The guaranteed ammonia solution pressure at the ammonia storage area BL is minimum 5 barg and maximum 7 barg. A mean operating pressure of 6 barg is assumed. Therefore, the pressure regulating valve in the ammonia circulation loop shall provide a minimum backpressure of 60 mWC +/- 10 mWC under all operating conditions.

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Pressure losses in the circuit guarantee a working pressure of ammonia to the SCR evaporator skid that fulfills the required working pressure range: 5-7 barg, as per doc PBCFU6003702 “Fusina CGGT, BOP Fluid List”

Ammonia circulation pumps (76HSJ21AP100 / 76HSJ22AP100) will have the following characteristics:

Q = 1200 L/h

H = 60 mWC

All flowrates in the operating range of the SCR are covered with the ammonia circulation loop flow.

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6 AMMONIA UNLOADING SYSTEM

6.1 Unloading tank (76HSJ10BB100)

The unloading tank (76HSJ10BB100) is provided as buffer between the truck and the storage tanks (76HSJ21BB100 / 76HSJ22BB100). It's volume and geometry prevent cavitation in the unloading pumps (76HSJ11AP100 / 76HSJ12AP100). The tank will be vented to the fume scrubber (76HSJ30BB100).

Unloading tank (76HSJ10BB100) design criteria:

- Tank volume: 3 m³ useful volume
- Duty: 1 x 100%
- Venting system: to fume scrubber (76HSJ30BB100)
- Design pressure: 0,45 barg (overpressure) / 0,05 barg (vacuum)
- Design temperature: 50°C
- Material: AISI 304L

6.2 Ammonia solution unloading pumps (76HSJ11AP100 / 76HSJ12AP100)

The ammonia unloading station includes no. 2 pumps, working in a 2 x 100% configuration. The pumps are capable of unloading a truck (30 m³) in no more than 30 min.

The following data is used for pump sizing:


- Unloading piping level difference: ~8 m (to be confirmed after piping layout)
- Pump delivery pipe length: ~30 m (to be confirmed after piping layout)
- Pump delivery pipe size: 3"
- Additional backpressure elements: 4 mWC
- Design flow: 60 m³/h

With the above information the pump head is evaluated as → ~ 17,5 mWC
which is approximated to 20 mWC.

Ammonia unloading pumps (76HSJ11AP100 / 76HSJ12AP100) will have the following characteristics:

$$Q = 60 \text{ m}^3/\text{h}$$

$$H = 20 \text{ mWC}$$

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6.3 Ammonia unloading drain pumps (76HSJ41AP200 / 76HSJ42AP200)

The ammonia solution area includes no. 2 drain pumps (76HSJ41AP200 / 76HSJ42AP200), working in a 2 x 100% configuration, necessary to deliver potential liquid discharges in the area into the final discharge basin. Drain pumps (76HSJ41AP200 / 76HSJ42AP200) shall be able to evacuate the maximum water flowrate in the area coming from the ammonia abatement system, ~18m³/h.

The following data is used for pump sizing:


- Drain piping level difference: ~1 m (to be confirmed after piping layout)
- Pump delivery pipe length: ~40 m (to be confirmed after piping layout)
- Pump delivery pipe size: 2"
- Additional backpressure elements: 6 mWC
- Design flow: 20 m³/h

With the above information the pump head is evaluated as → ~ 14,5 mWC
which is approximated to 15 mWC.

Ammonia unloading drain pumps (76HSJ41AP200 / 76HSJ42AP200) will have the following characteristics:

$$Q = 20 \text{ m}^3/\text{h}$$

$$H = 15 \text{ mWC}$$

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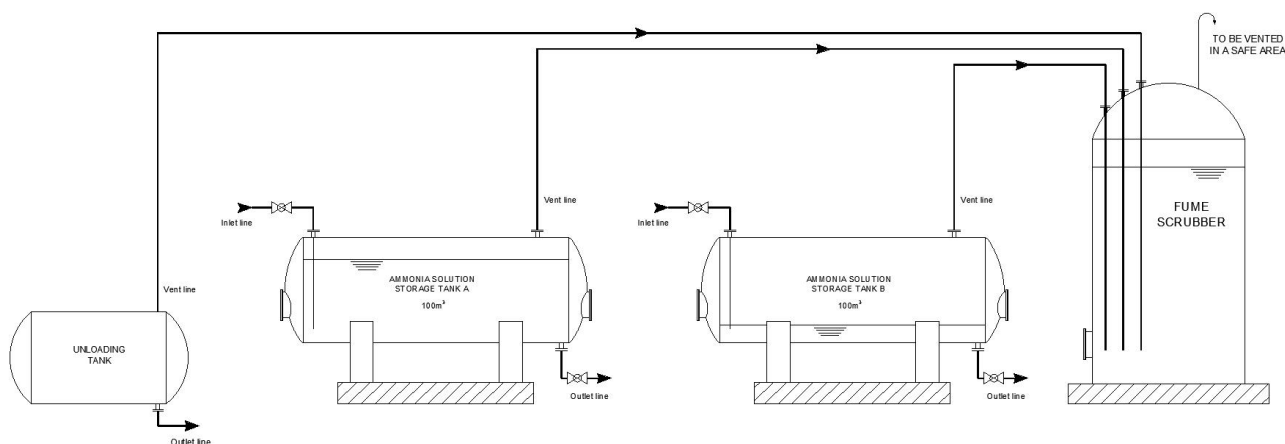
7 FUME SCRUBBER (76HSJ30BB100) SYSTEM

7.1 Fume scrubber (76HSJ30BB100)

The fume scrubber (76HSJ30BB100) is a demi water filled tank to which the vented gases from the unloading tank (76HSJ10BB100) and both ammonia solution storage tanks (76HSJ21BB100 / 76HSJ22BB100) are directed. The vent lines are placed under a demi water column to avoid direct ammonia vapors discharge into the atmosphere. As the gases from the tanks pass through the fume scrubber (76HSJ30BB100), ammonia vapors are dissolved in the water and the ammonia concentration inside the fume scrubber (76HSJ30BB100) increases.

According to the project's specifications, the fume scrubber (76HSJ30BB100) shall be sized so that a maximum ammonia concentration of 5%w/w is reached in 2 months, considering the unit in continuous operation at MCR with design NO_x content, T according to each site's environmental conditions and an ammonia solution concentration of 25%w/w.


The following image represents the fume scrubber and tanks' situation:



Fume scrubber (76HSJ30BB100) and tanks' scheme

Venting of gases from the tanks can occur due to a temperature increase of the tank's contents which leads to the expansion of the gaseous phase and/or boiling of the ammonia solution. Venting due to heat-up may be estimated by application of the Ideal Gas Law while boiling can be verified using vapor-liquid equilibrium principles. Emissions are calculated using the following assumptions:

- The vented gas is assumed to be saturated with the volatile phase vapor (ammonia-water in this case) in equilibrium with the liquid phase.
- One storage tank is in use ("active") while the other one is in "stand-by" with only a minimum volume of ammonia solution inside of it.
- The unloading tank (76HSJ10BB100) during normal operation is empty and no ammonia emissions come from this tank.
- Ammonia vapors from both storage tanks (76HSJ21BB100 / 76HSJ22BB100) will be vented to the fume scrubber (76HSJ30BB100).

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- During a 2-month period, considering the unit in continuous operation at MCR, the ammonia solution volume inside the active storage tank will vary from the maximum to the minimum level, and in between. An average value of the gas-phase volume inside the active storage tank during this period can be assumed to be half the useful volume of the tank, i.e. 50m³.
- The gas-phase volume inside the storage tank in “stand-by” mode is assumed to be 90% of the total useful volume, i.e. 90m³.
- The maximum air temperature (+40°C) is reached only 10% of the days during a 2-month period, i.e. 6 days.
- For all other days, i.e. 55 days, and based on the historic data of June, July, August and September 2021, a mean maximum air temperature of 32°C is assumed to be reached every day.
- The lowest temperature reached during nighttime for all days in the 2-month period is assumed to be 15°C.
- No direct sunlight reaches the storage tanks (76HSJ21BB100 / 76HSJ22BB100) and the only heat source that raises the temperature of the contents inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) is the ambient air.
- Contents in the tanks, both liquid and gas, reach thermal equilibrium with the ambient air.

The following process data is known:

- The fume scrubber (76HSJ30BB100)’s liquid column height above the gas discharge is 4m, which provides a counterpressure for gas venting of 1,4bara
- During normal operation, all tanks are maintained at a minimum pressure of 1,05 bara using nitrogen. However, due to thermal expansion of vapors inside the tanks, pressure can increase up to the maximum fume scrubber (76HSJ30BB100) counterpressure i.e. 1,4bara before being vented.

Thermal expansion of vapors inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) can be estimated using the Ideal Gas Law and partial pressures of water and ammonia for the initial and final temperatures. The calculation will initially be carried out for the days reaching 40°C (313.15K).

Tables 2-21 and 2-23 of the Perry’s Chemical Engineer’s Handbook present the vapor pressure of water and ammonia respectively for a water-ammonia mixture at different temperatures and different ammonia concentrations. Considering an initial temperature of 15°C, a final temperature of 40°C and an ammonia concentration of 25%w/w, through extrapolation, the following is obtained:


$$P_{vap_{H_2O}}@15^{\circ}C = 0,0128 \text{ bar}$$

$$P_{vap_{NH_3}}@15^{\circ}C = 0,4164 \text{ bar}$$

and

$$P_{vap_{H_2O}}@40^{\circ}C = 0,0535 \text{ bara}$$

$$P_{vap_{NH_3}}@40^{\circ}C = 1,1347 \text{ bara}$$

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The total vapor pressure of the mixture is the sum of the vapor pressure of the two species. It can be observed from the data above that:

$$P_{vap_{mixture}}@40^{\circ}C = 1,1882 \text{ bara}$$

With this value and knowing that the maximum counterpressure of the fume scrubber (76HSJ30BB100) is 1,4 bara, it can be concluded that the mixture inside the tanks will not boil, even at the maximum ambient temperature in site. No ammonia venting is expected from the ammonia solution boiling inside the storage and unloading tank (76HSJ10BB100)s.

However, venting due to thermal gas expansion can occur and is calculated next.

For simplicity of calculation, the storage tanks (76HSJ21BB100 / 76HSJ22BB100) will be initially considered as closed containers heated from an initial temperature of 15°C up to a final temperature of 40°C. A second calculation step will consider the gas-volume increase inside the active storage tank due to consumption of ammonia solution in the evaporation unit, under continuous operation at MCR (400L/h). This gas-volume increase will result in a slight decrease of the final pressure inside the storage tank. The resulting pressure will then need to be discharged to balance with the maximum counterpressure of the fume scrubber (76HSJ30BB100) (1,4 bara). Discharging pressure will mean a mass of gas being discharged which can be translated to kg of ammonia into the fume scrubber (76HSJ30BB100).


Nitrogen is used for blanketing of the storage tanks (76HSJ21BB100 / 76HSJ22BB100); therefore, the gas-phase volume of the storage tanks will be a mixture of nitrogen, gaseous ammonia, and water vapor in equilibrium. Nitrogen is a non-condensable gas which will be affected by temperature according the Ideal Gas Law while gaseous ammonia and water vapor concentrations in the gas-phase will depend only on the vapor pressure of each species at the given temperature. This means the total gas pressure inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) can be described by Dalton's Law of Partial Pressure which states that the total pressure inside a vessel with a mixture of gases that don't react among them, is the sum of the partial pressures of each gas species.

Initially, the partial pressure of N₂ in the tanks at the minimum ambient temperature will be:

$$P_{N_2_{initial}} = P_{Total_{initial}} - P_{vap_{H_2O}}@15^{\circ}C - P_{vap_{NH_3}}@15^{\circ}C$$

$$P_{N_2_{initial}} = 1,05 \text{ bara} - 0,0128 \text{ bara} - 0,4164 \text{ bar}$$

$$P_{N_2_{initial}} = 0,6208 \text{ bara}$$

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When heating the storage tanks (76HSJ21BB100 / 76HSJ22BB100) up to 40°C, nitrogen's pressure can be found following the Ideal Gas Law :

$$P_{N_2_initial} V_{N_2_initial} = n_{N_2_initial} R T_{N_2_initial}$$

$$P_{N_2_40^\circ C} V_{N_2_40^\circ C} = n_{N_2_40^\circ C} R T_{N_2_40^\circ C}$$

Assuming no changes in volume of the gas phase and no changes in mass/mol quantity occurs during the heating process, it can be said that:

$$\frac{P_{N_2_initial} V_{N_2_initial}}{R T_{N_2_initial}} = \frac{P_{N_2_40^\circ C} V_{N_2_40^\circ C}}{R T_{N_2_40^\circ C}}$$

Simplifying and solving for the pressure of nitrogen expected inside the tank at 40°C, the following is obtained:

$$P_{N_2_40^\circ C} = P_{N_2_initial} \left(\frac{T_{N_2_40^\circ C}}{T_{N_2_initial}} \right)$$

Therefore, the pressure of nitrogen will be:

$$P_{N_2_40^\circ C} = 0,6208 \text{ bara} \left(\frac{313,15K}{288,15K} \right) = 0,6747 \text{ bara}$$

Following once again Dalton's Law of Partial Pressure, the total pressure inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) at 40°C will be:

$$P_{Total_40^\circ C} = P_{N_2_40^\circ C} + P_{vap_{H_2O}}@40^\circ C + P_{vap_{NH_3}}@40^\circ C$$


$$P_{Total_40^\circ C} = 0,6747 \text{ bara} + 0,0535 \text{ bara} + 1,1347 \text{ bara}$$

$$P_{Total_40^\circ C} = 1,8629 \text{ bara}$$

Assuming the heating process of the storage tanks (76HSJ21BB100 / 76HSJ22BB100) occurs during a period of 8h (from the morning, until the hottest hours of the day), a volume increase of the gas phase will occur due to consumption of ammonia solution. The calculation considers the evaporation unit operating at MCR, which means an ammonia solution consumption rate of 400L/h. In 8 hours, the total volume of ammonia solution used will be 3,2m³. Following the Ideal Gas Law, the new pressure inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) will be:

$$P_{new_40^\circ C} = P_{Total_40^\circ C} \left(\frac{V_{initial}}{V_{initial} + 3,2m^3} \right)$$

$$P_{new_40^\circ C} = 1,8629 \text{ bara} \left(\frac{V_{initial}}{V_{initial} + 3,2m^3} \right)$$

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From the assumptions, the initial gas-phase volume is known to be $50\text{m}^3 + 90\text{m}^3 = 140\text{m}^3$. Therefore:

$$P_{new_40^\circ\text{C}} = 1,8629 \text{ bara} \left(\frac{140\text{m}^3}{143,2\text{m}^3} \right)$$

$$P_{new_40^\circ\text{C}} = 1,8212 \text{ bara}$$

Since the maximum pressure inside the tanks due to thermal expansion is expected to be 1,8212 bara (assuming the storage tanks (76HSJ21BB100 / 76HSJ22BB100) to be closed vessels with a maximum gas volume increase of $3,2\text{m}^3$), and the maximum counterpressure from the fume scrubber (76HSJ30BB100) is 1,4 bara, some gas is expected to vent from the tanks through the fume scrubber (76HSJ30BB100) until the pressures equalize.

According to the Ideal Gas Law, and assuming the final gas volume and temperature inside the tanks remain constant, the total number of moles remaining inside the tanks at a pressure of 1,4 bara will be:

$$\frac{n_{initial}RT_{@MaxPressure}}{P_{@MaxPressure}} = \frac{n_{@1,4bara}RT_{@1,4bara}}{P_{@1,4bara}}$$

$$n_{@1,4bara} = n_{initial} \left(\frac{P_{@1,4bara}}{P_{@MaxPressure}} \right)$$

$$n_{@1,4bara} = n_{initial} \left(\frac{1,4bara}{1,8212 \text{ bara}} \right) = 0,769 * n_{initial}$$

Which means 23,1% of the initial number of moles will be vented to the fume scrubber (76HSJ30BB100) in one day.

Assuming liquid/vapor equilibrium is reached at 40°C and 1,4bara, a mixture of nitrogen, water vapor and gaseous ammonia with the following partial pressures will be found inside the tanks:

$$P_{H_2O} = 0,0535 \text{ bara}$$

$$P_{NH_3} = 1,1347 \text{ bara}$$


$$P_{N_2} = 1,4 - 0,0535 - 1,1347 = 0,2118 \text{ bara}$$

Which translates into the following mole fractions:

$$y_{H_2O} = 0,038$$

$$y_{NH_3} = 0,811$$

$$y_{N_2} = 0,151$$

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From the Ideal Gas Law, the initial number of gas moles inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100) can be found:

$$n_{initial} = \frac{P_{initial} V_{initial}}{RT_{initial}}$$

$$n_{initial} = \frac{1,05 \text{ bara} * 140 \text{ m}^3}{R * 288,15 \text{ K}}$$

$$n_{initial} = 6136 \text{ moles}$$

With this information, it is possible to find the vented ammonia to the fume scrubber (76HSJ30BB100) in one day:

$$Vented \text{ NH}_3 [kg/day] @ 40^\circ C = 0,232 * n_{initial} * y_{\text{NH}_3} * MW_{\text{NH}_3} / 1000$$

$$Vented \text{ NH}_3 [kg/day] @ 40^\circ C = 0,232 * 6136 \text{ moles} * 0,811 * 17 g/mol / 1000 g/kg$$

$$Vented \text{ NH}_3 [kg/day] @ 40^\circ C = 19,55 kg/day$$

Based on the initial assumptions, the ambient temperature reaches 40°C only 6 days during a 2-month period. Therefore, the total mass of ammonia vented to the fume scrubber (76HSJ30BB100) these 6 days will be:

$$Total \text{ vented } \text{ NH}_3 [kg] @ 40^\circ C = 19,55 kg/day * 6_{days}$$

$$Total \text{ vented } \text{ NH}_3 [kg] @ 40^\circ C = 117,3 kg$$


For all other days (55 days) over a 2-month period, the calculations above are repeated considering a maximum air temperature of 32°C, based on the mean historical data of the hottest months of the year for 2021. In this case, the following parameters are considered:

$$P_{vap_{H_2O}} @ 32^\circ C = 0,0342 \text{ bara}$$

$$P_{vap_{NH_3}} @ 32^\circ C = 0,8317 \text{ bara}$$

The resulting vented ammonia to the fume scrubber (76HSJ30BB100) in one day is:

$$Vented \text{ NH}_3 [kg/day] @ 32^\circ C = 3,72 kg/day$$

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And the total mass of ammonia vented to the fume scrubber (76HSJ30BB100) these 55 days will be:

$$Total\ vented\ NH_3[kg]@ 32^{\circ}C = 3,72kg/day * 55_{days}$$

$$Total\ vented\ NH_3[kg]@32^{\circ}C = 204,4\ kg$$

During the whole 2-month period, the total mass of ammonia vented to the fume scrubber (76HSJ30BB100) is:

$$Total\ vented\ NH_3[kg/2\ months] = Total\ vented\ NH_3[kg]@40^{\circ}C + Total\ vented\ NH_3[kg]@32^{\circ}C$$

$$Total\ vented\ NH_3[kg/2\ months] = 117,3\ kg + 204,4\ kg$$

$$Total\ vented\ NH_3[kg/2\ months] = 321,7\ kg$$


Therefore, to reach a maximum ammonia concentration level of 5%w/w inside the fume scrubber (76HSJ30BB100) during this period, the minimum water volume needed is:

$$Minimum\ water\ volume\ in\ fume\ scrubber = \left(\frac{Total\ vented\ NH_3[kg/2\ months]}{0,05} \right) / 1000kg/m^3$$

$$Minimum\ water\ volume\ in\ fume\ scrubber = \left(\frac{321,7kg}{0,05} \right) / 1000kg/m^3$$

$$Minimum\ water\ volume\ in\ fume\ scrubber = 6,4m^3$$

A fume scrubber (76HSJ30BB100) with a useful water volume of 10 m³ will be designed to ensure a complete fulfillment of ammonia abatement requirements.

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7.2 Ammonia Recovery pumps (76HSJ31AP100 / 76HSJ32AP100)

The ammonia recovery station includes no. 2 pumps, working in a 2 x 100% configuration. The required pump flowrate is 10 m³/h.

The following data is used for pump sizing:


- Storage tank height (piping highest point): 5 m
- Pump delivery pipe length: 50 m (to be confirmed after piping layout)
- Pump delivery pipe size: 3"
- Additional backpressure elements 10 mWC
- Design flow: 10 m³/h

With the above information the pump head is evaluated as → ~ 15,3 mWC
which is approximated to 20 mWC.

Ammonia recovered pumps will have the following characteristics:

$$Q = 10 \text{ m}^3/\text{h}$$

$$H = 20 \text{ mWC}$$


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8 NITROGEN SYSTEM

Nitrogen blanketing is required to maintain a minimum positive pressure inside the storage tanks (76HSJ21BB100 / 76HSJ22BB100).

8.1 Nitrogen consumption

Nitrogen compensates for the ammonia solution volume being withdrawn from the storage tanks (76HSJ21BB100 / 76HSJ22BB100). With the SCR unit in operation at MCR, the ammonia solution consumption is 400 L/h. At nominal ambient temperature (15°C) and 0,05 barg (pressure setpoint for final nitrogen pressure reducing valve), N₂ consumption will be 400 L/h. Considering 10% losses, the maximum N₂ consumption is approximately 0,44 Nm³/h.

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9 CONTAINMENT SYSTEM

9.1 Storage tanks (76HSJ21BB100 / 76HSJ22BB100) Containment Basin and Final Discharge Basin

Both storage tanks (76HSJ21BB100 / 76HSJ22BB100) and the fume scrubber (76HSJ30BB100) are installed inside a concrete basin. This basin shall be sized so it is able to contain at least 1,5 times the maximum volume of one storage tank.

The total geometric volume of the concrete basin for the project is approximately 225 m³.

This basin discharges by gravity to the Final Discharge Basin, sized to contain one truck volume (30m³) plus an additional volume of firefighting water.

For the current project, the Final Discharge Basin useful volume is defined to be 70 m³.

9.2 Sump pumps (76HSJ41AP100 / 76HSJ42AP100)

The Final Discharge Basin is equipped with no. 2 pumps, working in a 2 x 100% configuration. The required pump flowrate is 30 m³/h.

The following data is used for pump sizing:

- Static head difference between sump and truck connection: 4,5 m
- Pump delivery pipe length: 50 m (to be confirmed after piping layout)
- Pump delivery pipe size: 3"
- Design flow: 30 m³/h
- Additional backpressure elements: 5 mWC

With the above information the pump head is evaluated as → ~ 12,1 mWC
which is approximately 15 mWC.

Sump pumps (76HSJ41AP100 / 76HSJ42AP100) will have the following characteristics:

$$Q = 30 \text{ m}^3/\text{h}$$

$$H = 15 \text{ mWC}$$